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(54) **PASSIVE EMBEDDED INTERACTION CODING**

(75) Inventors: **Jian Wang**, Beijing (CN); **Yingnong Dang**, Beijing (CN); **Jiang Wu**, Beijing (CN); **Xiaoxu Ma**, Beijing (CN)

(73) Assignee: **Microsoft Corporation**, Redmond, WA (US)

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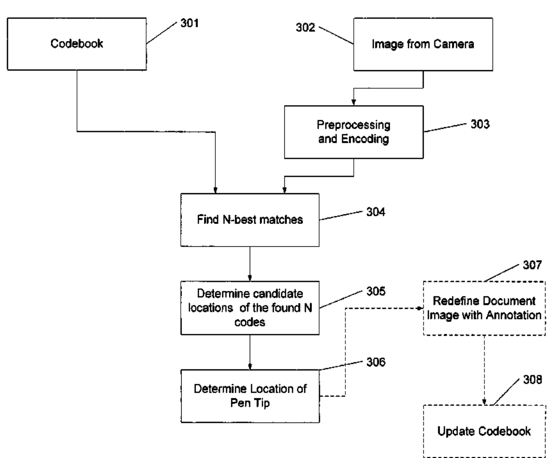
Primary Examiner—Duy M Dang
(74) *Attorney, Agent, or Firm*—Perkins Coie LLP

(57) **ABSTRACT**

A system and method for encoding a document image and finding a location based on that image are described. A document page is encoded into codes associated with various locations of the document page. The codes are assembled into a code book. Captured images may then be similarly encoded and searched against the codes in the codebook. One or more codes and associated locations may be returned, thereby providing one or more possible locations for the captured images.

18 Claims, 8 Drawing Sheets



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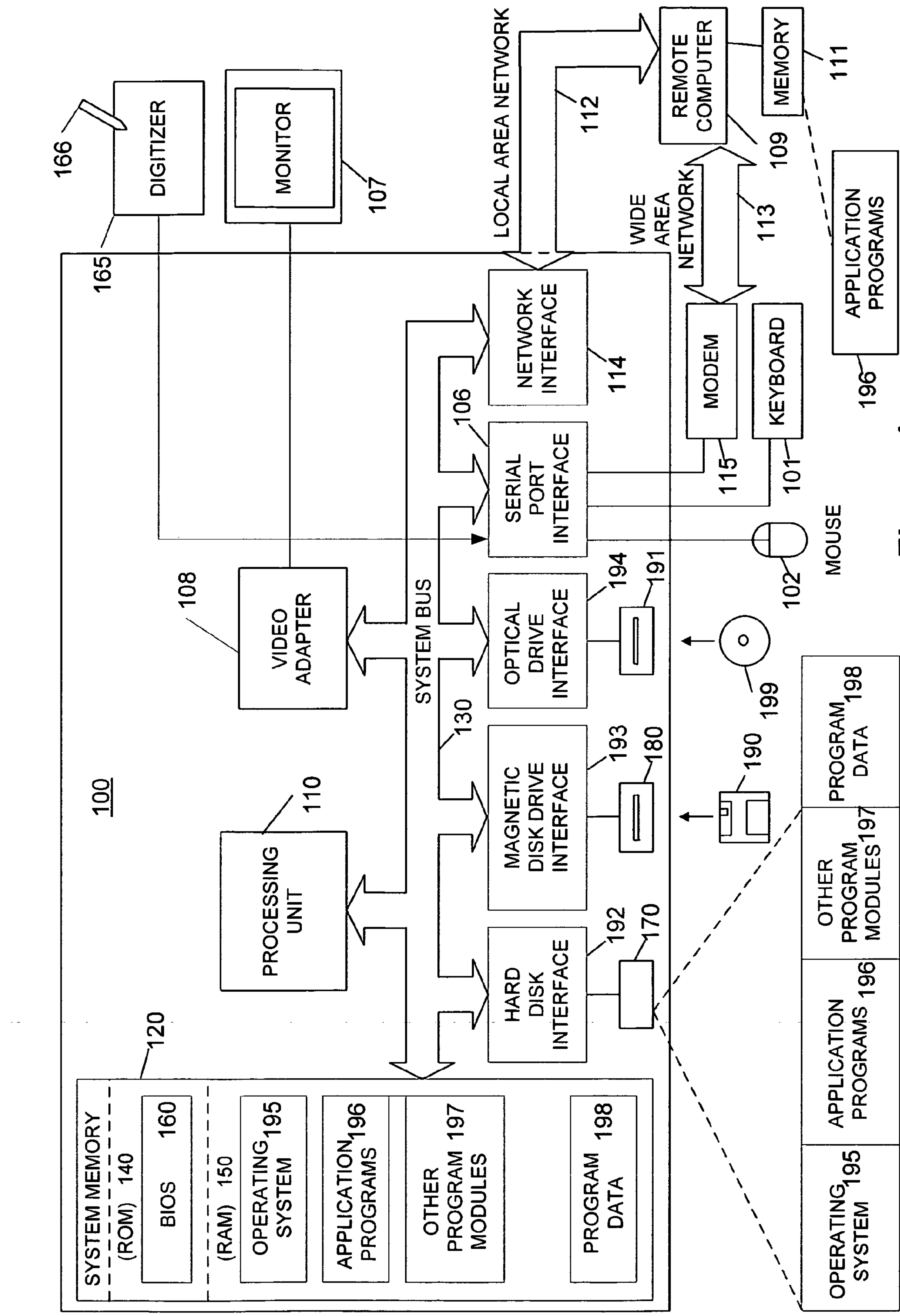

100
SYSTEM MEMORY
(ROM) 140
BIOS 160
(RAM) 150
OPERATING SYSTEM 195
APPLICATION PROGRAMS 196
OTHER PROGRAM MODULES 197
PROGRAM DATA 198
120
PROCESSING UNIT
110
VIDEO ADAPTER
108
SYSTEM BUS
130
HARD DISK INTERFACE
192
170
MAGNETIC DISK DRIVE INTERFACE
193
180
OPTICAL DRIVE INTERFACE
194
191
SERIAL PORT INTERFACE
106
NETWORK INTERFACE
114
DIGITIZER
165
166
MONITOR
107
LOCAL AREA NETWORK
112
WIDE AREA NETWORK
113
REMOTE COMPUTER
109
MEMORY
111
MODEM
115
KEYBOARD
101
MOUSE
102
190
199
APPLICATION PROGRAMS
196
OPERATING SYSTEM 195
APPLICATION PROGRAMS 196
OTHER PROGRAM MODULES 197
PROGRAM DATA 198

Figure 1

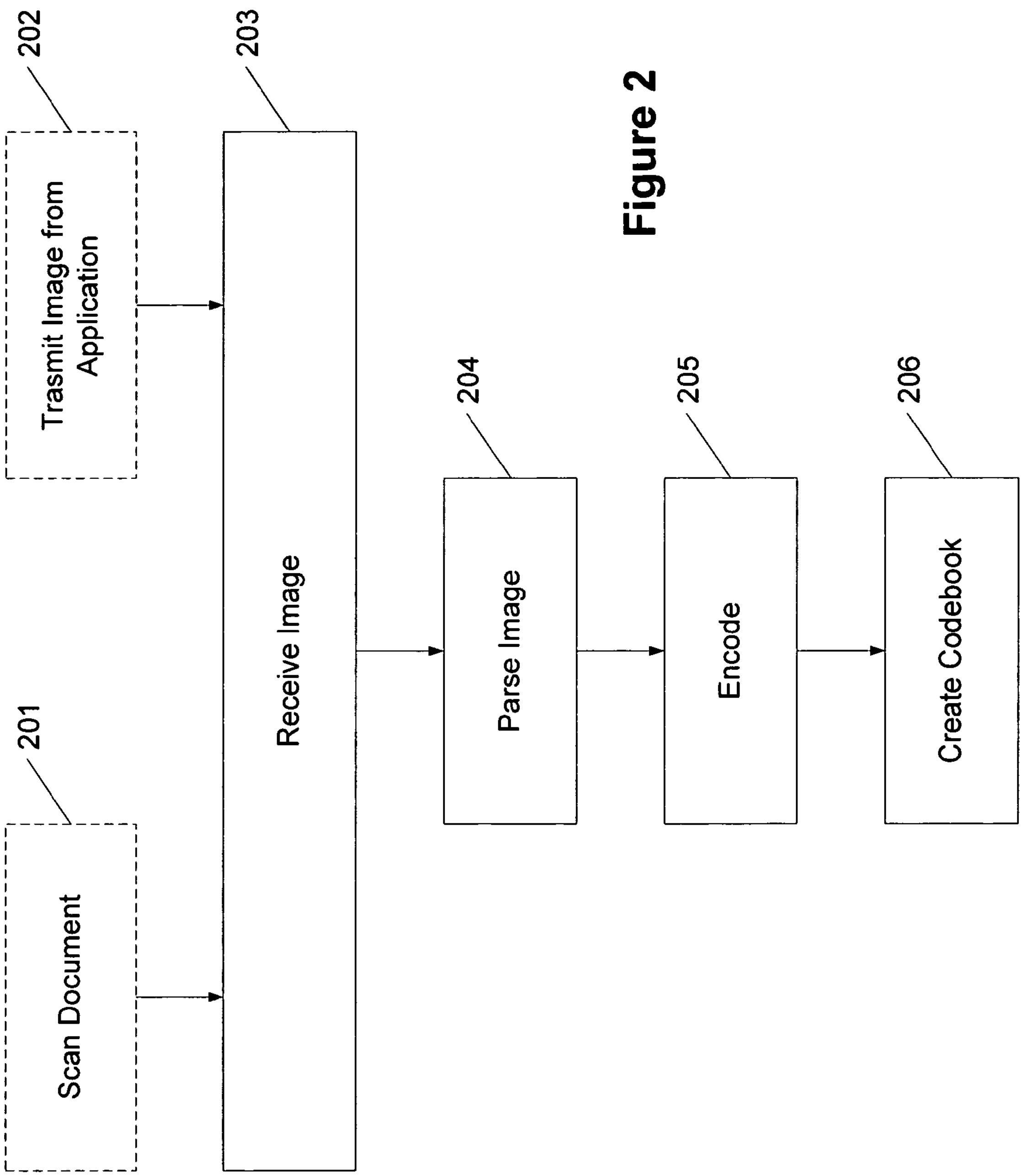
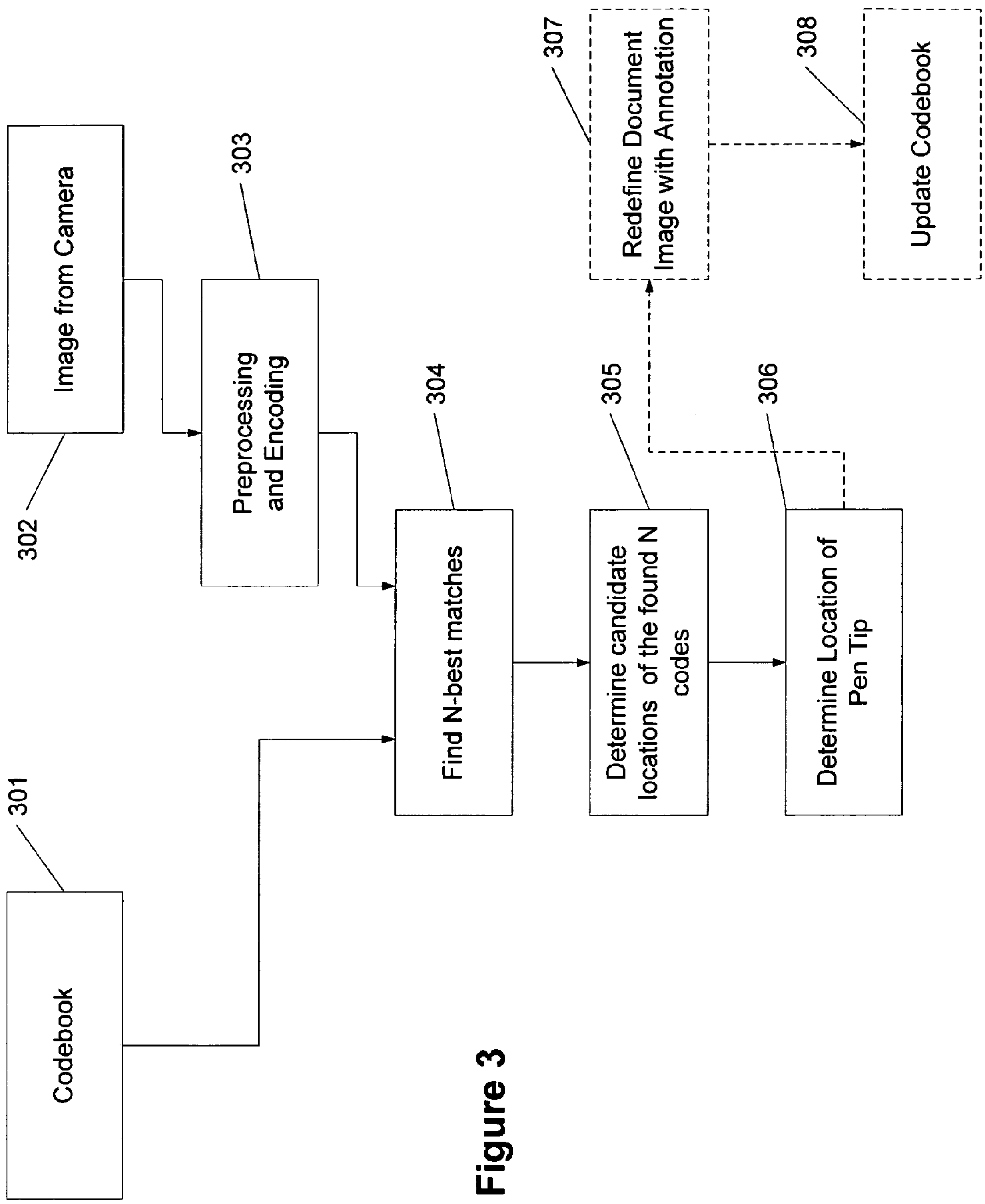

Scan Document
201
Trasmit Image from Application
202
Receive Image
203
Parse Image
204
Encode
205
Create Codebook
206

Figure 2



301
Codebook
302
Image from Camera
303
Preprocessing and Encoding
304
Find N-best matches
305
Determine candidate locations of the found N codes
306
Determine Location of Pen Tip
307
Redefine Document Image with Annotation
308
Update Codebook

Figure 3

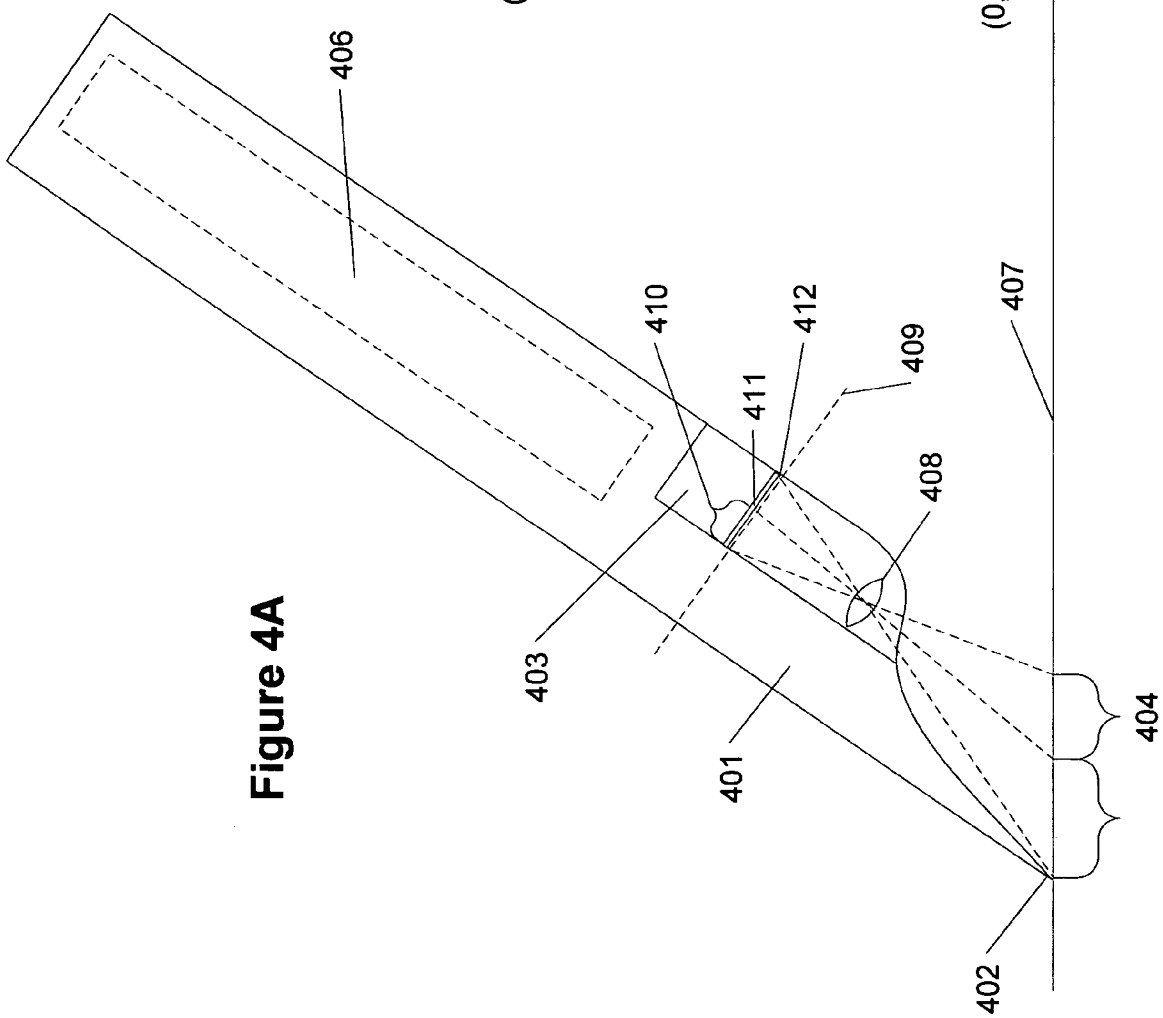


Figure 4A

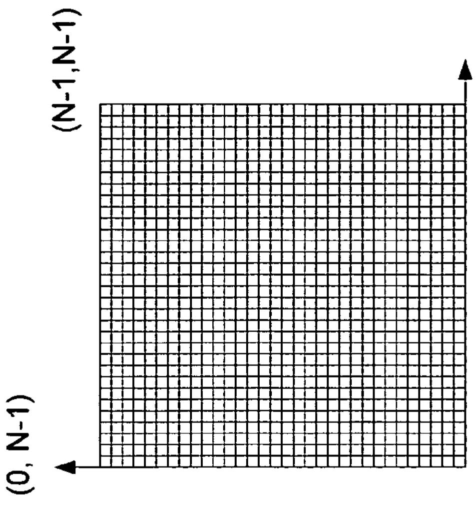


Figure 4B

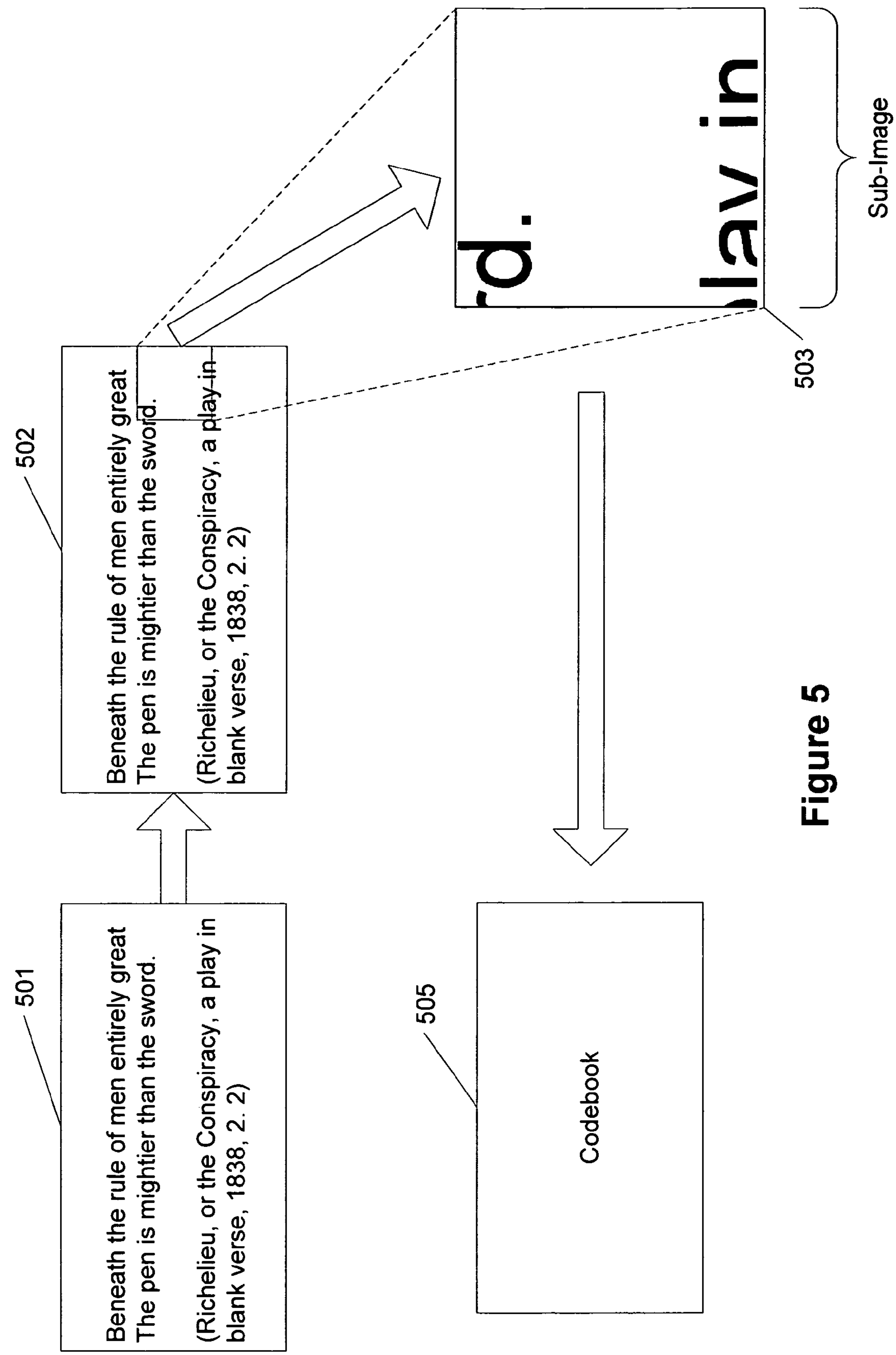

501
Beneath the rule of men entirely great
The pen is mightier than the sword.
(Richelieu, or the Conspiracy, a play in
blank verse, 1838, 2. 2)
502
Beneath the rule of men entirely great
The pen is mightier than the sword.
(Richelieu, or the Conspiracy, a play in
blank verse, 1838, 2. 2)
rd.
lay in
Sub-Image
503
505
Codebook

Figure 5

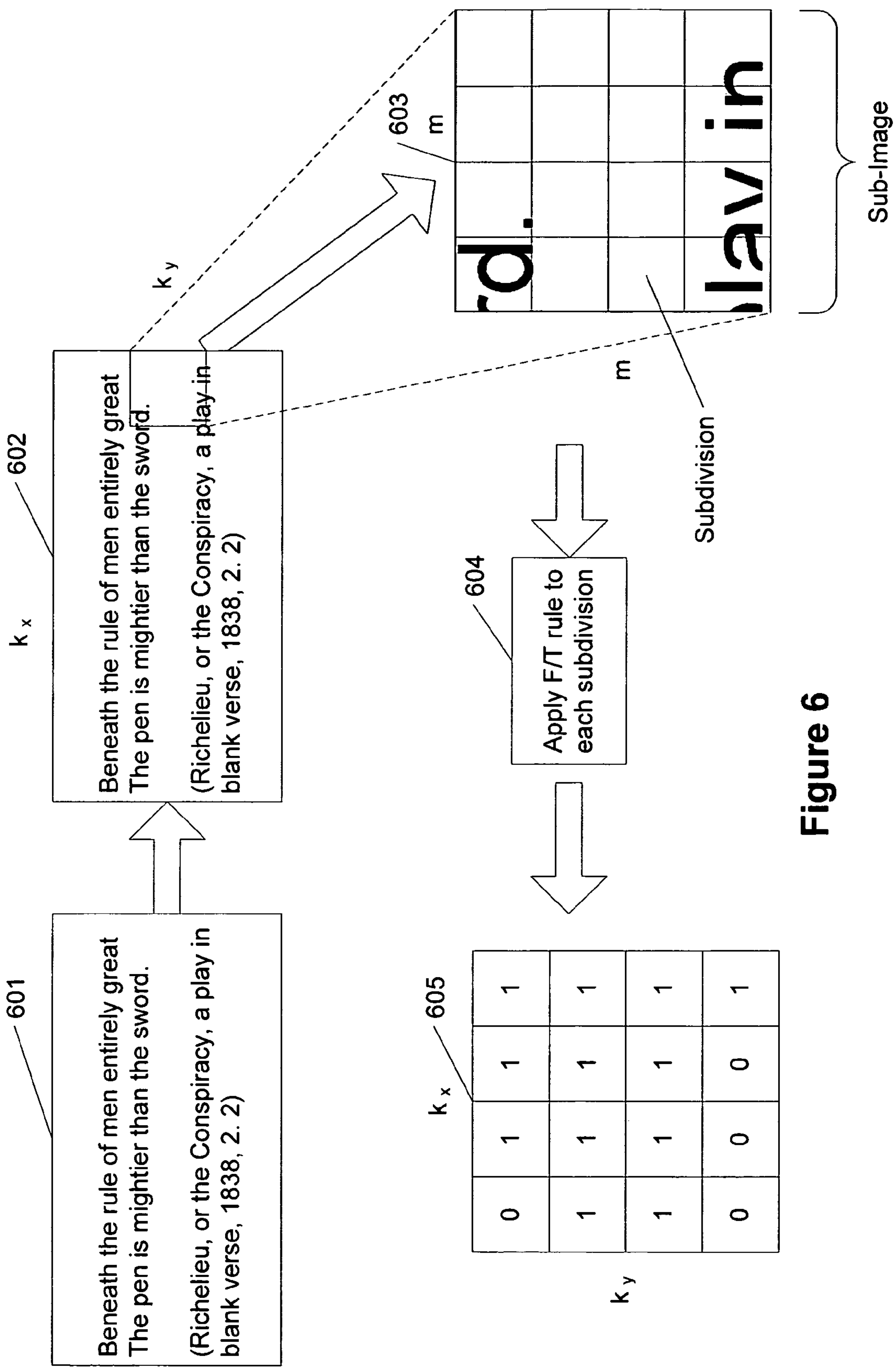
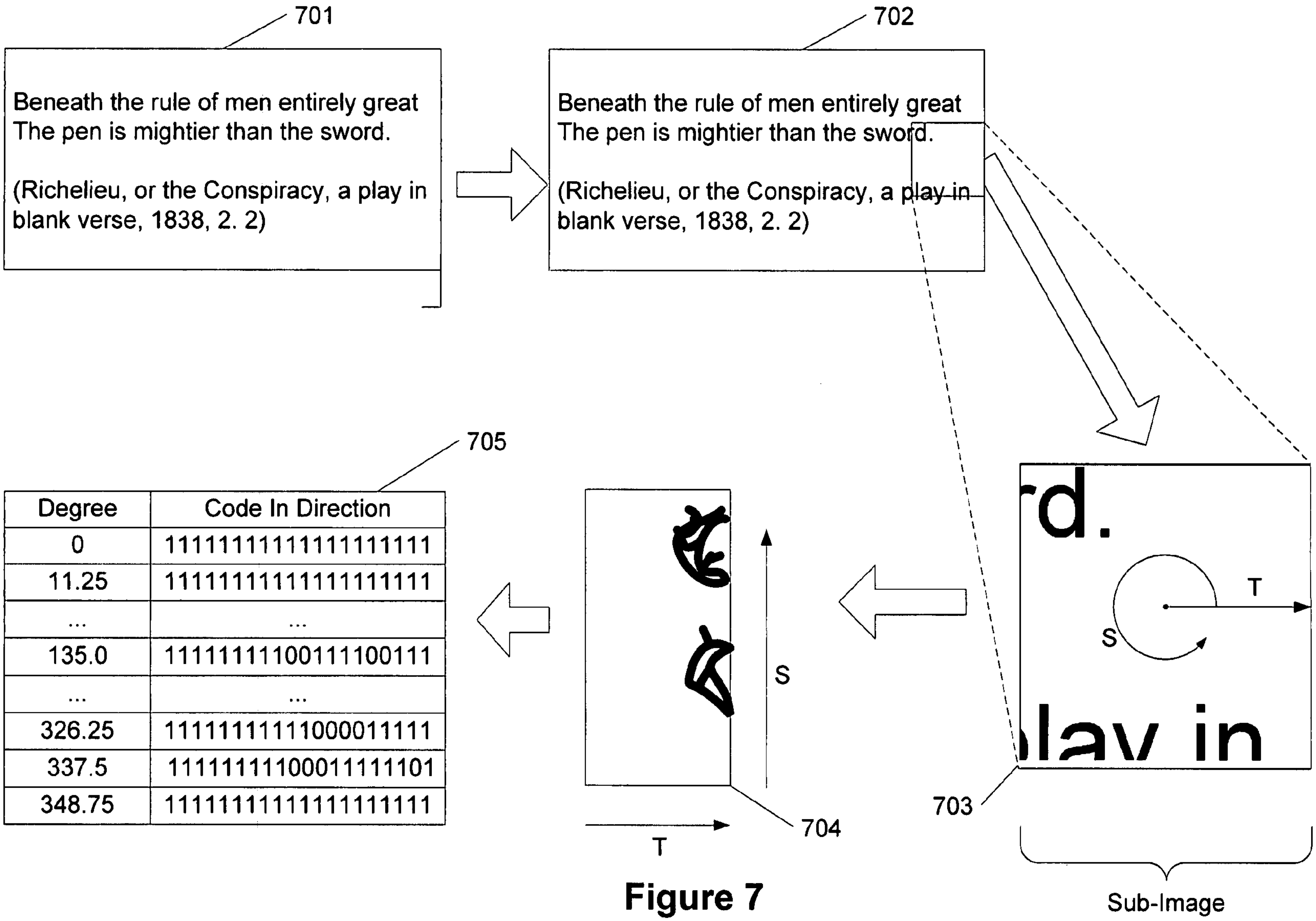

601
Beneath the rule of men entirely great
The pen is mightier than the sword.
(Richelieu, or the Conspiracy, a play in blank verse, 1838, 2. 2)
602
Beneath the rule of men entirely great
The pen is mightier than the sword.
(Richelieu, or the Conspiracy, a play in blank verse, 1838, 2. 2)
k x
k y
603
m
m
rd.
play in
Sub-Image
Subdivision
604
Apply F/T rule to each subdivision
605
k x
k y
0 1 1 1
1 1 1 1
1 1 1 1
0 0 0 1

Figure 6



Degree	Code In Direction
0	11111111111111111111
11.25	11111111111111111111
...	...
135.0	11111111100111100111
...	...
326.25	11111111111000011111
337.5	11111111100011111101
348.75	11111111111111111111

Figure 7

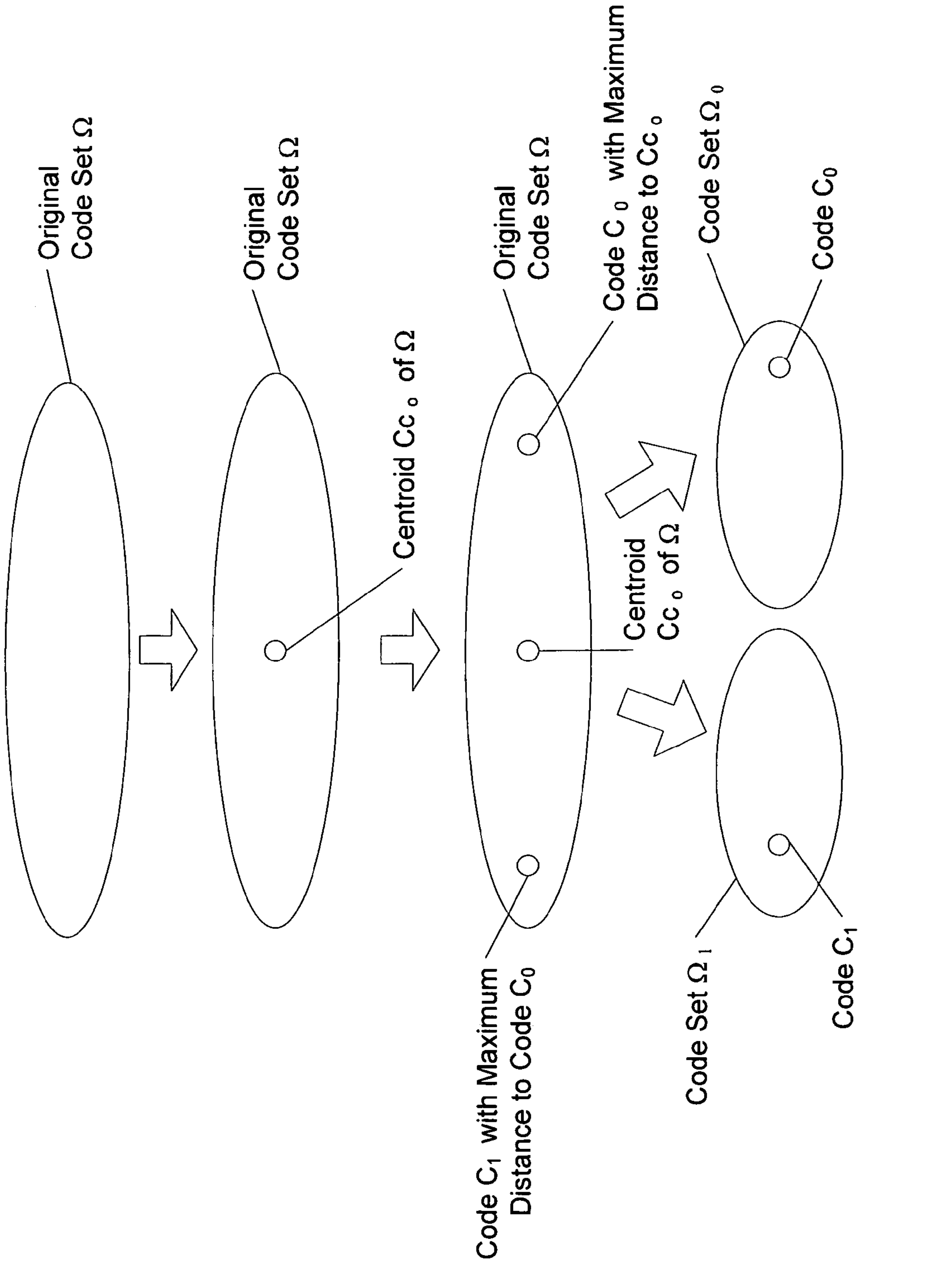

Original Code Set Ω
Original Code Set Ω
Centroid Cc_0 of Ω
Original Code Set Ω
Code C_0 with Maximum Distance to Cc_0
Centroid Cc_0 of Ω
Code C_1 with Maximum Distance to Code C_0
Code Set Ω_0
Code C_0
Code Set Ω_1
Code C_1

Figure 8

PASSIVE EMBEDDED INTERACTION CODING

CROSS REFERENCE TO RELATED APPLICATION

This application is a divisional of U.S. application Ser. No. 10/284,451, filed Oct. 31, 2002, now U.S. Pat. No. 7,133,563, of the same title.

TECHNICAL FIELD

The present invention relates to interacting with paper using a digital pen. More particularly, the present invention relates to determining the location of annotations made on paper by a digital pen.

BACKGROUND

Computer users are accustomed to using a mouse and keyboard as a way of interacting with a personal computer. While personal computers provide a number of advantages over written documents, most users continue to perform certain functions using printed paper. Some of these functions include reading and annotating written documents. In the case of annotations, the printed document assumes a greater significance because of the annotations placed on it by the user. One of the difficulties, however, with having a printed document with annotations is the later need to have the annotations entered back into the electronic form of the document. This requires the original user or another user to wade through the annotations and enter them into a personal computer. In some cases, a user will scan in the annotations and the original text, thereby creating a new document. These multiple steps make the interaction between the printed document and the electronic version of the document difficult to handle on a repeated basis. Further, scanned-in images are frequently non-modifiable. There may be no way to separate the annotations from the original text. This makes using the annotations difficult. Accordingly, an improved way of handling annotations is needed.

SUMMARY

Aspects of the present invention provide solutions to at least one of the issues mentioned above, thereby enabling one to locate a position or positions on a viewed image. Knowledge of these positions permits a user to write annotations on a physical document and have those annotations associated with an electronic version of the physical document. Some aspects of the invention relate to the various techniques used to encode the physical document. Other aspects relate to the organization of the encoded document in searchable form.

These and other aspects of the present invention will become known through the following drawings and associated description.

BRIEF DESCRIPTION OF DRAWINGS

The foregoing summary of the invention, as well as the following detailed description of preferred embodiments, is better understood when read in conjunction with the accompanying drawings, which are included by way of example, and not by way of limitation with regard to the claimed invention.

FIG. **1** shows a general description of a computer that may be used in conjunction with embodiments of the present invention.

FIG. **2** shows a process for parsing the received image and creating a codebook in accordance with embodiments of the present invention.

FIG. **3** shows a process for determining one or more possible locations of an image from a camera in accordance with embodiments of the present invention.

FIG. **4** shows a possible view of a pen and image capture system in accordance with embodiments of the present invention.

FIG. **5** shows a first process for encoding an image in accordance with embodiments of the present invention.

FIG. **6** shows a second process for encoding an image in accordance with embodiments of the present invention.

FIG. **7** shows a third process for encoding an image in accordance with embodiments of the present invention.

FIG. **8** shows an illustration of the construction of a codebook in accordance with embodiments of the present invention.

DETAILED DESCRIPTION

Aspects of the present invention relate to determining the location of a captured image in relation to a larger image. The location determination method and system described herein may be used in combination with a multi-function pen. This multifunction pen provides the ability to capture handwritten annotations that are made on a fixed document, then having the annotations locatable with the information on the fixed document. The fixed document may be a printed document or may be a document rendered on a computer screen.

The following is arranged into a number of subsections to assist the reader in understanding the various aspects of the invention. The subsections include: terms, general purpose computer; locating captured image; encoding; codebook generation; and candidate search.

Terms

Pen—any writing implement that may or may not include the ability to store ink. In some examples a stylus with no ink capability may be used as a pen in accordance with embodiments of the present invention.

Camera—an image capture system.

Encoding—a process by taking an image (either scanned in from a physical paper form or rendered from an electronic form) or from a camera and modifying it in some way.

Codebook—a storage that stores an encoded image or encoded sub-images.

General Purpose Computer

FIG. **1** is a functional block diagram of an example of a conventional general-purpose digital computing environment that can be used to implement various aspects of the present invention. In FIG. **1**, a computer **100** includes a processing unit **110**, a system memory **120**, and a system bus **130** that couples various system components including the system memory to the processing unit **110**. The system bus **130** may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures. The system memory **120** includes read only memory (ROM) **140** and random access memory (RAM) **150**.

A basic input/output system **160** (BIOS), containing the basic routines that help to transfer information between elements within the computer **100**, such as during start-up, is stored in the ROM **140**. The computer **100** also includes a hard disk drive **170** for reading from and writing to a hard disk (not shown), a magnetic disk drive **180** for reading from or writing to a removable magnetic disk **190**, and an optical disk drive **191** for reading from or writing to a removable optical disk **199** such as a CD ROM or other optical media. The hard disk drive **170**, magnetic disk drive **180**, and optical disk drive **191** are connected to the system bus **130** by a hard disk drive interface **192**, a magnetic disk drive interface **193**, and an optical disk drive interface **194**, respectively. The drives and their associated computer-readable media provide nonvolatile storage of computer readable instructions, data structures, program modules and other data for the personal computer **100**. It will be appreciated by those skilled in the art that other types of computer readable media that can store data that is accessible by a computer, such as magnetic cassettes, flash memory cards, digital video disks, Bernoulli cartridges, random access memories (RAMs), read only memories (ROMs), and the like, may also be used in the example operating environment.

A number of program modules can be stored on the hard disk drive **170**, magnetic disk **190**, optical disk **199**, ROM **140** or RAM **150**, including an operating system **195**, one or more application programs **196**, other program modules **197**, and program data **198**. A user can enter commands and information into the computer **100** through input devices such as a keyboard **101** and pointing device **102**. Other input devices (not shown) may include a microphone, joystick, game pad, satellite dish, scanner or the like. These and other input devices are often connected to the processing unit **110** through a serial port interface **106** that is coupled to the system bus, but may be connected by other interfaces, such as a parallel port, game port or a universal serial bus (USB). Further still, these devices may be coupled directly to the system bus **130** via an appropriate interface (not shown). A monitor **107** or other type of display device is also connected to the system bus **130** via an interface, such as a video adapter **108**. In addition to the monitor, personal computers typically include other peripheral output devices (not shown), such as speakers and printers. In a preferred embodiment, a pen digitizer **165** and accompanying pen or stylus **166** are provided in order to digitally capture freehand input. Although a direct connection between the pen digitizer **165** and the serial port is shown, in practice, the pen digitizer **165** may be coupled to the processing unit **110** directly, via a parallel port or other interface and the system bus **130** as known in the art. Furthermore, although the digitizer **165** is shown apart from the monitor **107**, it is preferred that the usable input area of the digitizer **165** be co-extensive with the display area of the monitor **107**. Further still, the digitizer **165** may be integrated in the monitor **107**, or may exist as a separate device overlaying or otherwise appended to the monitor **107**.

The computer **100** can operate in a networked environment using logical connections to one or more remote computers, such as a remote computer **109**. The remote computer **109** can be a server, a router, a network PC, a peer device or other common network node, and typically includes many or all of the elements described above relative to the computer **100**, although only a memory storage device **111** has been illustrated in FIG. **1**. The logical connections depicted in FIG. **1** include a local area network (LAN) **112** and a wide area network (WAN) **113**. Such networking environments are commonplace in offices, enterprise-wide computer networks, intranets and the Internet.

When used in a LAN networking environment, the computer **100** is connected to the local network **112** through a network interface or adapter **114**. When used in a WAN networking environment, the personal computer **100** typically includes a modem **115** or other means for establishing a communications over the wide area network **113**, such as the Internet. The modem **115**, which may be internal or external, is connected to the system bus **130** via the serial port interface **106**. In a networked environment, program modules depicted relative to the personal computer **100**, or portions thereof, may be stored in the remote memory storage device.

It will be appreciated that the network connections shown are illustrative and other techniques for establishing a communications link between the computers can be used. The existence of any of various well-known protocols such as TCP/IP, Ethernet, FTP, HTTP and the like is presumed, and the system can be operated in a client-server configuration to permit a user to retrieve web pages from a web-based server. Any of various conventional web browsers can be used to display and manipulate data on web pages.

Locating Captured Image

Aspects of the present invention include storing and encoded version of a document in a searchable form. When an annotating device (for example, a pen with a camera attached for capturing a sub-image of a document) is used to write annotations, the system permits a determination of the location of the camera. This determination of the location of the camera may be used to determine the location of where the annotation is located. In some aspects of the present invention, the pen may be an ink and writing on paper. In other aspects, the pen may be a stylus with the user writing on the surface of a computer display. In this latter example, the annotations written on the computer screen may be provided back to the system supporting the document displayed on the computer screen. By repeatedly capturing the location of the camera, the system can track movement of the stylus being controlled by the user.

To determine location of a captured image, three processes may be used. In practice, however, aspects of these three processes may be combined into less than three processes or separated into more than three processes. The first process relates to encoding the image into a searchable form. In one example, the image is encoded into a searchable form and associated with a location of the image (for example, the center coordinates of the image). The location of the center of a captured image may be in any position of the document image. Any sub-image (with a center in any position of the document image) may be encoded. This provides the benefit that the various positions of the document image may be encoded so that any possible position (at which the captured image can be located) is stored in a codebook and may be searched.

The second process relates to compiling the encoded image or sub-image into a searchable structure. The third process relates to searching the encoded sets of information to determine a location of a camera's image with respect to the original document. Subsequent processing may then be used to determine the location of a stylus pen tip in relation to the image from the camera.

Referring to FIG. **2**, an image of a document is received in step **203**. The image of the document received in step **203** may result from the scan of a paper document in step **201**. Alternatively, the image of step **203** may originate from an application in step **202**.

In step **204**, the image is parsed into sub-images. In step **205**, the sub-images are converted into a searchable form with their corresponding location attached, namely, some position-code pairs are obtained. Accordingly, each location with integer pixel units has a corresponding code. In step **206**, the encoded datasets with position-code pairs from step **205** are arranged in a searchable codebook, which is indexed with the property of codes.

Referring to FIG. **3**, a codebook is searched for an image corresponding to one from the camera. The image from the camera may be approximately the size of the sub-images from a larger image. Making the sub-images approximately the same size of the image from the camera permits faster searching. Otherwise, scaling the camera to the sub-image size, scaling the sub-image to a camera image size, or some combination of both types of scaling may be used to compare the images. In step **304**, an image from a camera from step **302** is compared with datasets from the codebook **301**. The comparison step of **304** may include finding the N best codes that exceed a threshold between the codebook data **301** and the captured images **302**. The image from camera in step **302** may be used directly in step **304** or may undergo preprocessing and encoding in step **303**. The preprocessing of step **303** may include converting grayscale images into binary, black and white images. The preprocessing may account for rotation, skewing, white level balance, quantization error, perspective correction and the like. The encoding of step **303** means applying similar processing as step **205** to the image from the camera (step **302**).

Next, in step **305**, the location candidates of the found N codes (exceeding the threshold). The code obtained from step **303** is compared with the codes in the codebook, and the codes best matched with the code from step **303** are kept. From the location of the image as determined in step **305**, the location of the pen tip is determined in step **306**. Optionally, as shown in broken boxes, new annotations may be processed in step **307** and the codebook updated in step **308**. The process of adding back the annotations may improve the ability of the system to locate a camera frame when the user is writing on or near preexisting annotations.

This determination of the location of a captured image may be used to determine the location of a user's interaction with the paper, medium, or display screen. In some aspects of the present invention, the pen may be an ink pen writing on paper. In other aspects, the pen may be a stylus with the user writing on the surface of a computer display. Any interaction may be provided back to the system with knowledge of the encoded watermark on the document or supporting the document displayed on the computer screen. By repeatedly capturing the location of the camera, the system can track movement of the stylus being controlled by the user.

FIGS. **4**A and **4**B show an illustrative example of pen **401** with a camera **403**. Pen **401** includes a tip **402** that may or may not include an ink reservoir. Camera **403** captures an image **404** from surface **407**. Pen **401** may further include additional sensors and/or processors as represented in broken box **406**. These sensors and/or processors **406** may also include the ability to transmit information to another pen **401** and/or a personal computer (for example, via Bluetooth or other wireless protocols).

FIG. **4**B represents an image as viewed by camera **403**. In one illustrative example, the field of view of camera **403** is 32×32 pixels (where N=32). Accordingly, FIG. **4**B shows a field of view of 32 pixels long by 32 pixels wide. The size of N is adjustable based on the degree of image resolution desired. Also, while the field of view of the camera **403** is shown as a square for illustrative purposes here, the field of view may include other shapes as is known in the art.

The input to the pen **401** from the camera **403** may be defined as a sequence of image frames {Ii}, i=1, 2, . . . , A, where Ii is captured by the pen **401** at sampling time ti. The sampling rate may be fixed or may be variable based on the size of the document. The size of the captured image frame may be large or small, depending on the size of the document and the degree of exactness required. Also, the camera image size may be determined based on the size of the document to be searched.

The image captured by camera **403** may be used directly by the processing system or may undergo pre-filtering. This pre-filtering may occur in pen **401** or may occur outside of pen **401** (for example, in a personal computer).

The image size of FIG. **4**B is 32×32 pixels. If each encoding unit size is 3×3 pixels, then the number of captured encoded units would be approximately 100 units. If the encoding unit size is 5×5, then the number of captured encoded units is approximately 36.

The output of camera **403** may be compared with encoded information in the codebook. The codebook may be created from a color, grayscale, or black and white scan of an image. Alternatively, the codebook may be generated from an image output by an application or a received image. The output of the comparison of the codebook with sequence {Ii} may be represented as a sequence {Pi}, i=1, 2, . . . , A, where Pi represents all possible position candidates of pen tip **402** in document bitmap at sampling time ti.

FIG. **4**A also shows the image plane **409** on which an image **410** of the pattern from location **404** is formed. Light received from the pattern on the object plane **407** is focused by lens **408**. Lens **408** may be a single lens or a multi-part lens system, but is represented here as a single lens for simplicity. Image capturing sensor **411** captures the image **410**.

The image sensor **411** may be large enough to capture the image **410**. Alternatively, the image sensor **411** may be large enough to capture an image of the pen tip **402** at location **412**. For reference, the image at location **412** is referred to as the virtual pen tip. It is noted that the virtual pen tip location with respect to image sensor **411** is fixed because of the constant relationship between the pen tip **402**, the lens **408**, and the image sensor **411**. Because the transformation from the location of the virtual pen tip **412** (represented by $L_{virtual\text{-}pentip}$) to the location of the real pen tip **402** (represented by L_{pentip}), one can determine the location of the real pen tip **402** in relation to a captured image **410**.

The following transformation $F_{S\rightarrow P}$ transforms the image captured by camera to the real image on the paper:

$$L_{paper}=F_{S\rightarrow P}(L_{Sensor})$$

During writing, the pen tip and the paper are on the same plane. Accordingly, the transformation from the virtual pen tip to the real pen tip is also $F_{S\rightarrow P}$:

$$L_{pentip}=F_{S\rightarrow P}(L_{virtual\text{-}pentip})$$

The transformation $F_{S\rightarrow P}$ may be referred to as a perspective transformation. This simplifies as:

$$F'_{S\rightarrow P}=\begin{Bmatrix} s_x\cos\theta, & s_y\sin\theta, & 0 \\ -s_x\sin\theta, & s_y\cos\theta, & 0 \\ 0, & 0, & 1 \end{Bmatrix}$$

as the estimation of $F_{S\rightarrow P}$, in which θ, s_x, and s_y are the rotation and scale of two orientations of the pattern captured at location **404**. Further, one can refine $F'_{S\rightarrow P}$ to $F_{S\rightarrow P}$ by matching the captured image with the corresponding background image on paper. Further, one can refine $F'_{S\rightarrow P}$ to $F_{S\rightarrow P}$ by matching the captured image with the corresponding background image on paper. "Refine" means to get a more precise perspective matrix $F_{S\rightarrow P}$ (8 parameters) by a kind of optimization algorithm referred to as a recursive method. The recursive method treats the matrix $F'_{S\rightarrow P}$ as the initial value. $F_{S\rightarrow P}$ describes the transformation between S and P more precisely than $F'_{S\rightarrow P}$.

Next, one can determine the location of virtual pen tip by calibration.

One places the pen tip **402** on a known location L_{pentip} on paper. Next, one tilts the pen, allowing the camera **403** to capture a series of images with different pen poses. For each image captured, one may receive the transform $F_{S\rightarrow P}$. From this transform, one can obtain the location of the virtual image of pen tip $L_{virtual\text{-}pentip}$:

$$L_{virtual\text{-}pentip}=F_{P\rightarrow S}(L_{pentip})$$

And,

$$F_{P\rightarrow S}=1/F_{S\rightarrow P}$$

By averaging the $L_{virtual\text{-}pentip}$ received from every image, an accurate location of the virtual pen tip $L_{virtual\text{-}pentip}$ may be determined.

The location of the virtual pen tip $L_{virtual\text{-}pentip}$ is now known. One can also obtain the transformation $F_{S\rightarrow P}$ from image captured. Finally, one can use this information to determine the location of the real pen tip L_{pentip}:

$$L_{pentip}=F_{S\rightarrow P}(L_{virtual\text{-}pentip})$$

Encoding

The image to be encoded may come from a scanner scanning a document. Alternatively, the image to be encoded may be in a fixed, electronic form (for example, an electronic file with a fixed display size with only read-only privileges). While the document may indeed be modifiable, for locating a position of a camera, the version encoded may generally correspond to the document viewed by camera **403**. Otherwise, correlation may still occur but the codebook may not be as accurate as with a similarity between the scanned document and the images from the camera.

The image is parsed into sub-images. Each sub-image is encoded into an easily searchable form. The sub-images may be set to the same size as the output from camera **403**. This provides the benefit of roughly equal search comparisons between the output from camera **403** and the information stored in the codebook. Subsequent processing may be performed on the resulting location to locate annotations on the input image and/or control other operations of a computing system based in the scanned image.

The following presents a number of different coding options, which may be used to generate a codebook. The image captured from the camera while using pen **401** may also be encoded using one of the following encoding methods so as to facilitate comparison of the information in the codebook and the encoded information from the camera. A variety of encoding systems are possible. Three are provided here; however, other encoding techniques may be used.

Simple Coding

A first type of coding includes using the parsed sub-images from a received image themselves to act as the code. FIG. **5** shows an example of this process. An input image **501** is parsed into sub-images in step **502**. The sub-images (represented by **503**) are associated with their locations in the image **501** and stored in codebook **505**. When searching the codebook **505**, an image from the camera **403** is compared with one or more stored sub-images in codebook **505**. One or more candidates may be provided from the comparison. Further, the location of the pen tip **402** may be determined.

Reduced Size Coding

Another encoding example includes reducing the size of each sub-image. First, image **601** is received. Image **601** may be represented as image block I. Image block I, in some cases, may be converted into a binary image I_b by applying a threshold to image block I. Next, the sub-images may be represented generically by K_x*K_y with each sub-image being of size m*m as in **602-603**. In the example of FIG. **6**, m=4. In another example, m=32 where the sub-image is separated into a 32*32 grid, similar to the grid in FIG. **4**B.

Further, the subdivisions m of each sub-image do not need to directly correspond to the image resolution of a camera. For example, the subdivisions m may be combinations or partial combinations of smaller subdivisions. Here, if the smaller subdivisions number 32, and m=4 (from FIG. **6**), each subdivision m may contain 8 pixels.

Next, a rule-based analysis or threshold **604** (e.g., a true/false test) of the content of the subdivisions may be applied. An example of a threshold or rule to be applied to each subdivision in sub-image **603** may include a determination whether there are three contiguous white columns in each subdivision. Of course, other rule-based analyses may be used in place of or in conjunction with this example.

Based on the outcome of this analysis **604**, a matrix **605** may be generated. Matrix **605** shows an example of the outcome of threshold **604** as applied to each subdivision in sub-image **603**. The K matrix (K_x wide by K_y tall) has values 0/1 where 1 means true and 0 means false. The resulting K matrix may be expressed as $C_I^{k\text{-}win}$ of image block I, where k-win is another way of referring to the present coding method. $C_I^{k\text{-}win}$ may be represented as equation 1 with an example of a sub-image map as matrix **605**.

$$C_I^{k-win}=\begin{bmatrix} c_{11} & \cdots & c_{1K} \\ \vdots & \ddots & \vdots \\ c_{K1} & \cdots & c_{KK} \end{bmatrix} \quad (1)$$

This type of coding may be searched by determining the distance between a first matrix and a matrix formed from an image from camera **403**. The distance between two matrixes is the hamming distance of two matrixes as represented by equation 2.

$$Dist^{ham}(C_1, C_2)=Ham(C_1, C_2), \quad (2)$$

where Ham (a, b) is the hamming distance between matrix a and matrix b.

Radial Coding

Another type of coding, referred to as radial coding, is described with respect FIG. **7**. An image **701** is received and parsed into sub-images in step **702**. In **703**, the sub-image is sampled by rotating vector T about center of the sub-image in direction S. The encountered information in the sub-image of **703** is represented by unwrapped image **704**. In other words, the sub-image block of **703** is sampled in polar coordinates.

The center pixel (or region) of the sub-image in **703** is treated as the origin, the sampling angle is S, and the magnitude of the sampling vector is T. For a 32 by 32 pixel region, S=32 and T=16.

For each sampling point (t, s), t=0, 1, . . . , T−1, s=0, 1, . . . , S−1, its position in Cartesian coordinate is $(x_{t,s}, y_{t,s})$, where $x_{t,s}$ and $y_{t,s}$ are represented by Equations 3 and 4, respectively.

$$x_{t,s} = t\frac{N}{2T}\cos\left(s\cdot\frac{2\pi}{S}\right) \tag{3}$$

$$y_{t,s} = t\frac{N}{2T}\sin\left(s\cdot\frac{2\pi}{S}\right) \tag{4}$$

The gray level value of point (t, s) is represented by equation 5,

$$G_{t,s}=F(x_{t,s}, y_{t,s}), \tag{5}$$

where F is a 2-D Gaussian filter represented by equation 6.

$$F(x, y) = \frac{\sum_{i=-q}^{q}\sum_{j=-q}^{q} e^{\frac{-(([x]+i-x)^2+([y]+j-y)^2)}{\sigma^2}} P([x]+i, [y]+j)}{\sum_{i=-q}^{q}\sum_{j=-q}^{q} e^{\frac{-(([x]+i-x)^2+([y]+j-y)^2)}{\sigma^2}}}, \tag{6}$$

where P(x, y) means the gray level value of the pixel in position (x, y); the brackets "[ ]" means the nearest integers of a real value; σ and q are the filter parameters. Examples of the filter parameters may include σ=1.15, q=1. The values are determined by empirically testing the algorithms to determine which values work best for a given environment.

As polar coordinates are used to analyze the sub-image block as shown in **703**, the resulting analysis has a higher degree of robustness in handling rotation differences between the camera frame and the sub-images. The rotation of camera image to be compared with the information in the codebook is not a complex issue as rotation of the captured camera image translates to shifting of the image in **704**.

The image in **704** may be converted to its binary representation for each angle S across vector T as shown in table **705**. The degree is the value 2π·s/S as s ranges from 0 to S−1. The image or sub-images (**701**, **702**, **703**, **704**) may be converted at a number of locations to a binary (black and white) image, if not previously converted to binary image when initially scanned, received or captured.

The grey level value matrix $\{G_{t,s}\}$ (where t=0, 1, . . . , T−1, s=0, 1, . . . , S−1) may be converted to a binary matrix C_I^{rad} (as shown in equation 7) by applying a threshold to the values in the grey level matrix.

$$C_I^{rad} = \begin{bmatrix} c_{11} & \cdots & c_{1T} \\ \vdots & \ddots & \vdots \\ c_{S1} & \cdots & c_{ST} \end{bmatrix} \tag{7}$$

This code may then be compiled into a codebook with information relating to the location of the sub-images in the larger image.

To determine the location of a camera image with the different codes in the codebook, one may determine the distance between the camera image and the other code representations. The smallest distance or set of smallest distances to candidates may represent the best choice of the various locations. This distance may be computed by the hamming distance between the camera image and the current sub-images.

As set forth above, the distance from the captured image from the camera may be compared with one or more the code segments from the codebook. At least two types of distance may be used for the radial code: common hamming distance and rotation-invariant distance. Other distance determinations may be used.

The common hamming distance may be used as represented in equation 8 to determine the distance between a codebook code and a code associated with a camera image.

$$Dist^{ham}(C_1, C_2)=Ham(C_1, C_2), \tag{8}$$

Another type of distance that may be used includes a rotation-invariant distance. The benefit of using a rotation invariant distance is that the rotation of the camera is addressed as shown in equation 9.

$$Dist^{r-i}(C_1, C_2)=\min_{d=0,\ldots,S-1}(Ham(C_1,Rot(C_2,d))) \tag{9}$$

where $Rot(C_I^{rad},d)$ is defined as set forth in equation 10.

$$Rot(C_I^{rad}, d) = \begin{bmatrix} c_{d+1,1} & \cdots & c_{d+1,T} \\ \vdots & \ddots & \vdots \\ c_{S,1} & \cdots & c_{S,T} \\ c_{1,1} & \cdots & c_{1,T} \\ \vdots & \ddots & \vdots \\ c_{d,1} & \cdots & c_{d,T} \end{bmatrix} \tag{10}$$

Codebook Generation

The codebook stores the codes relating to sub-images taken from an image and associated with their locations in the image. The codebook may be created before capturing images with camera **403**. Alternatively, the codebook may be created or at least augmented during use. For example, the camera may pick up images during operation. If the user only writes on existing information as shown in Figure elements **501**, **601**, and **701**, then the codebook may be used as presently described to determine the location of the image captured by the camera. However if the user writes over new annotations, the codebook will not be as correct as it could be. Accordingly, when new annotations are added by pen **401**, these annotations may be incorporated back into the codebook so future annotations will be more accurately correlated with their on-screen representation.

Codebook generation may be as follows. The sub-images shown in **503**, **603**, and **703** are encoded by an encoding method. Next, the position-code pairs are organized to create the codebook. At least two types of organization methods may be used to create the codebook. Of course other methods may be used to create the codebook as well. These two methods are given as illustrative examples only.

The first method is to place the position-code pairs into a linear list in which each node contains a code and a position sequence where all positions are mapped to the code. The code book then may be represented as equation 11:

$$\Omega=\{\psi_i, i=1,2, \ldots, N_\Omega\} \tag{11}$$

where ψ is defined as $\psi=\{C_\psi, P_\psi\}$, P_ψ is the set of all positions in the document bitmap where its code is C is shown in equation 12:

$$P_\psi=\{p_i \mid \text{the code at position pi is } C_\psi, i=1,2, \ldots\}. \tag{12}$$

Next, the set Ω may be sorted by the code of each member ψ alphabetically, and then the codebook of the linear list type is obtained.

The second method is to place the codes with their corresponding locations into a binary tree.

The binary tree may be based on the Hamming distance between codes as represented by FIG. **8**. First, the centroid Cc_0 of the total code set Ω is found. Next, the code C_0 with the maximum hamming distance to the centroid Cc_0 is found. Next, the code C_1 with the maximum distance to code C_0 is found.

The code set C is then split into two subsets: Ω_0 and Ω_1. The contents of Ω_0 may be represented by equation 12 and the contents of Ω_1 represented by equation 13.

$$\Omega_0=\{\psi_i|Dist(C_{\psi_i}, C_0)<Dist(C_{\psi_i}, C_1)\} \quad (12)$$

$$\Omega_1=\{\psi_i|\psi_i\notin\Omega_0\} \quad (13)$$

Next, for subsets Ω_0 and Ω_1, the steps of founding the centroid, finding the code with the maximum distance to the centroid, finding the code with the maximum distance to the code farthest away from the centroid, then splitting the subset is repeated until the number of members of the subset is 1.

Candidate Search

The position candidates for a captured frame from the camera may be determined by searching the codebook. For each camera captured frame Ii, the candidate positions of the pen tip **402** may be determined as follows:

1) The frame Ii from the camera is encoded with the same encoding method used to generate the codebook;
2) The encoded frame E_{Ii} is compared with the information in the codebook. The distance between the encoded frame E_{Ii} and the encoded information in the codebook is determined. The encoded information in the codebook with the smallest distance to the encoded frame E_{Ii} is used as the position candidate or one of the position candidates. Of these candidates, the best match is chosen.

The choice for best candidates may include a number of different analyses. First, the candidate most closely matching (minimum distance to code E_{Ii}) may be selected. Alternatively, the most recent set of candidates may be compared with a recent sequence of candidates and compare the frames over time. The resultant comparison should result in a series of position locations that are closest to each other. This result is expected as it indicates that the pen tip moved as little as possible over time. The alternative result may indicate that the pen tip jumped around the page in a very short time (which is less probable).

For searching the codebook, the following may be used. For each captured image I, with code C_I, the best matched code set $S(C_I)$ is defined as equation 14.

$$S(C_I)=\{\psi_i|Dist(C_I,C_{\psi_i})<d_{thresh},\psi_i\in\Omega,i=1,\ldots,N_S\}, \quad (14)$$

if the radial code is used, the distance function should be $Dist^{r-i}(\cdot,\cdot)$.

Only N_{thresh} codes with less distance in $S(C_I)$ are kept, if $N_S>N_{thresh}$. d_{thresh} and N_{thresh} are selected based on the camera performance.

The set of position candidates for image I may be represented by equation (15).

$$P_I=\bigcup_{i=1}^{N_I}P_{\psi_i},\ \psi_i\in S(C_I) \quad (15)$$

Although the invention has been defined using the appended claims, these claims are illustrative in that the invention is intended to include the elements and steps described herein in any combination or sub combination. Accordingly, there are any number of alternative combinations for defining the invention, which incorporate one or more elements from the specification, including the description, claims, and drawings, in various combinations or sub combinations. It will be apparent to those skilled in the relevant technology, in light of the present specification, that alternate combinations of aspects of the invention, either alone or in combination with one or more elements or steps defined herein, may be utilized as modifications or alterations of the invention or as part of the invention. It may be intended that the written description of the invention contained herein covers all such modifications and alterations.

We claim:

1. A method performed by a computer having a memory and a processor for encoding information from a document image comprising steps of:

receiving a document image;

with a processor, parsing the document image into sub-images;

with a processor, adding information relating to the sub-images to a codebook; and

with a processor, applying a rule-based analysis to content of subdivisions of the sub-images

wherein the step of applying includes determining whether three contiguous white columns exist in a subdivision.

2. The method for encoding information according to claim **1**, further comprising a step of associating the sub-images with location information relating to where the sub-images are located in the document image.

3. The method for encoding information according to claim **2**, wherein the location information includes position-code pairs.

4. The method for encoding information according to claim **3**, wherein the codebook is searchable and indexed with a property of position-code pairs.

5. The method for encoding information according to claim **1**, further comprising a step of processing at least one of the sub-images, thereby creating a dataset that has less information than the at least one of the sub-images.

6. The method for encoding information according to claim **1**, further comprising a step of processing at least one of the sub-images by radial coding.

7. The method for encoding information according to claim **6**, wherein the step of processing includes sampling the at least one sub-image by rotating a vector about the center of the at least one sub-image in a counterclockwise direction.

8. The method for encoding information according to claim **7**, wherein the vector is a shortest distance from the center of the at least one sub-image to a side of the at least one sub-image.

9. The method for encoding information according to claim **1**, further comprising a step of image processing the sub-images.

10. The method for encoding information according to claim **1**, further comprising a step of converting the document image into a binary image.

11. A system for encoding information from a document image comprising:

an input configured to receive a document image;

a parser component configured to parse the document image into sub-images;

a codebook configured to store information relating to the sub-images; and

an analyzer configured to apply a rule-based analysis to content of subdivisions of the sub-images

wherein applying a rule-based analysis includes determining whether three contiguous white columns exist in a subdivision.

12. The system of claim **11**, further comprising a converter component configured to convert the sub-images into a searchable form with corresponding location information relating to where the sub-images are located in the document image.

13. The system of claim **12**, wherein the location information includes position-code pairs.

14. The system of claim **11**, further comprising a processor component configured to process at least one sub-image by radial coding.

15. The system of claim **14**, wherein the processor is configured to sample the at least one sub-image by rotating a vector about the center of the at least one sub-image in a counterclockwise direction.

16. The system of claim **15**, wherein the vector is a shortest distance from the center of the at least one sub-image to a side of the at least one sub-image.

17. One or more computer readable media storing executable instructions that, when executed by a computer having a memory and a processor, perform a method for encoding information from a document image, the method comprising steps of:

receiving a document image;

parsing the document image into sub-images;

adding information relating to the sub-images to a codebook; and

applying a rule-based analysis to content of subdivisions of the sub-images, wherein applying includes determining whether three contiguous white columns exist in a subdivision

wherein the parsing, adding, and applying are performed by the processor executing instructions stored in the memory.

18. The computer readable media of claim **17**, wherein the method further comprises a step of associating the sub-images with location information relating to where the sub-images are located in the document image.

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